A Contagion Model of Emergency Airplane Evacuations

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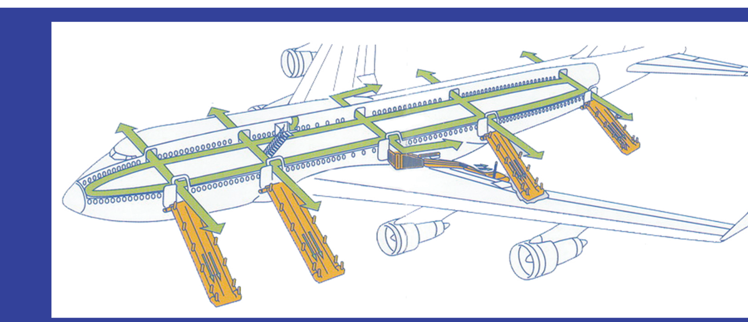


UCLA Applied Mathematics REU

Introduction

There are many examples in nature of organisms that congregate in large numbers such as flocks of birds, schools of fish or crowds of people. These large populations are comprised of individuals who are influenced by the group motion as well as their individual will. Researchers have extensively this type of studied swarming behavior (e.g. [1, 2]), but relatively few included emotion in their models. This project aims to understand the role of contagion in swarms or how information or emotion spreads among the individuals of a swarm. Inspired by the Asiana Flight 214 crash in San Francisco on July 6, 2013, the focus of this project is to model an emergency airplane evacuation. Our model is an adapted Particle Swarm Optimization (PSO) algorithm that includes the spread of emotion. The main feature of this algorithm is that each individual incorporates information about both the local and global landscape ~~to~~ to determine their direction of motion. The goal of this project is to study how this emotion impacts individuals and the entire group as they attempt to exit the aircraft. We hope that our models will lead to increased understanding of how panicked crowds behave in evacuation situations and which could lead to better, safer evacuation designs.

Particle Swarm Optimization

The Particle Swarm Optimization (PSO) algorithm as described in [3] models the position and velocity of agents moving toward a specific goal. In this case, the airplane emergency exits. An agent's position is compared to a fitness function that describes the current environment. Each agent then moves according to its knowledge of its own previous best position and the group's current best position. The static environment is modeled by a potential function that describes the layout of the airplane that includes the exits and physical barriers such as the seats. The algorithm has also been modified to include a repulsion force between agents that impede each other's physical space. The equations that model the movements of individual agents are given below. The position and velocity of the kth iteration of the ith particle are denoted $\mathbf{x}_k^i$ and $\mathbf{v}_k^i$ respectively.

$$\mathbf{x}_{k+1}^i = \mathbf{x}_k^i + \mathbf{v}_{k+1}^i \,\Delta t$$

$$\mathbf{v}_{k+1}^i = \underbrace{w\,\mathbf{v}_k^i}_{\text{current movement}} + \underbrace{c_1 U_k^1 h(\nabla f(\mathbf{x}_k^i))}_{\text{particle local search}} + \underbrace{c_2 U_k^2 h(p_k^g - \mathbf{x}_k^i)}_{\text{swarm influence}} - \underbrace{c_3 \textstyle\sum_{j\neq i} \text{Repel}(|\mathbf{x}_j - \mathbf{x}_i|)}_{\text{collisions}}$$

Here:

- $w =$ inertia factor,
- $c_1 =$ self confidence,
- $c_2 =$ swarm confidence,
- $c_3 =$ repulsion strength,
- $p_k^g =$ position of the particle with best global fitness at current move k,
- U_k^1 and U_k^2 are uniform random variables on $[0, 1]$,
- $h(\mathbf{u}) = \frac{\mathbf{u}}{C+|\mathbf{u}|}$ is a hill function that mollifies extreme gradients.
- $f(\mathbf{x})$ is the potential function for the plane.
- $\text{Repel}(r) = \frac{1}{r^2}$ is the repulsion force between two agents.

Contagion

Our model was also adapted to include the spread of an emotion such as fear or panic throughout the group of passengers on the plane. We added a variable q^i that stores the amount of emotion an individual feels during the simulation. The value of q^i ranges from 0 (calm) to 1 (extreme fear or panic). A difference in emotion with nearby agents will influence an individual's emotional state and thus emotion will spread throughout a crowd. In our simulations, an increase in fear in an agent will increase the force exerted on other agents and decrease the repulsion from obstacles such as airplane seats. The updated model to include emotion appears below.

$$\mathbf{x}_{k+1}^i = \mathbf{x}_k^i + \mathbf{v}_{k+1}^i \,\Delta t$$

$$\mathbf{v}_{k+1}^i = \underbrace{w\,\mathbf{v}_k^i}_{\text{current movement}} + \underbrace{c_1 U_k^1 h(\nabla f(\mathbf{x}_k^i))}_{\text{particle local search}} + \underbrace{c_2 U_k^2 h(p_k^g - \mathbf{x}_k^i)}_{\text{swarm influence}} - \underbrace{c_3 \textstyle\sum_{j\neq i} \frac{\text{Repel}(|\mathbf{x}_j - \mathbf{x}_i|)}{1+q_j-q_i}}_{\text{collisions}}$$

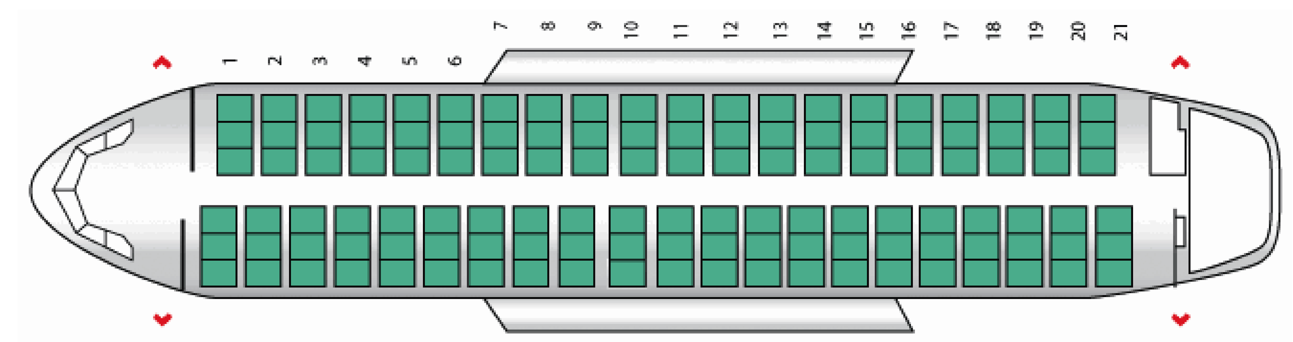
$$\dot{q}_i = -\gamma q_i + \frac{1}{N_\epsilon}\sum_{i=1}^{N_\epsilon} g(q_i - q_j)$$

Here:

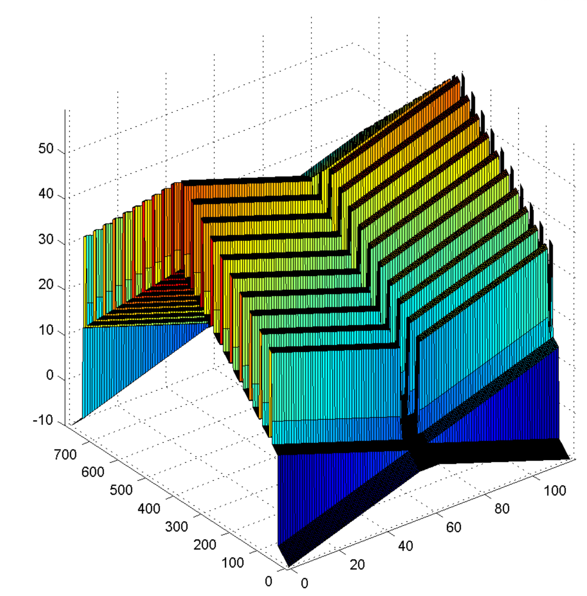
- $\gamma =$ emotion decay
- $g(q) = \begin{cases} \beta q & q > 0 \\ \frac{\beta}{2} q & q < 0 \end{cases}$ represents the agent to agent spread of emotion

Plane Landscape

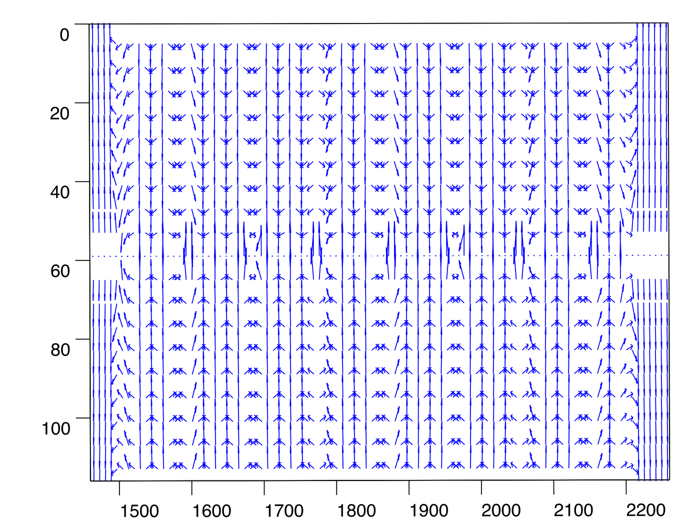
In order to guide passengers to the nearest exit, I constructed a function that describes the landscape of the airplane. As seen in the figure below, there are downward slopes from the seats into the nearest aisles as well as downward slopes from the aisles to the emergency exits. The airplane seats obstruct movement so that it is less likely, but still possible for passengers to climb over seats.



Seating Diagram



Airplane function

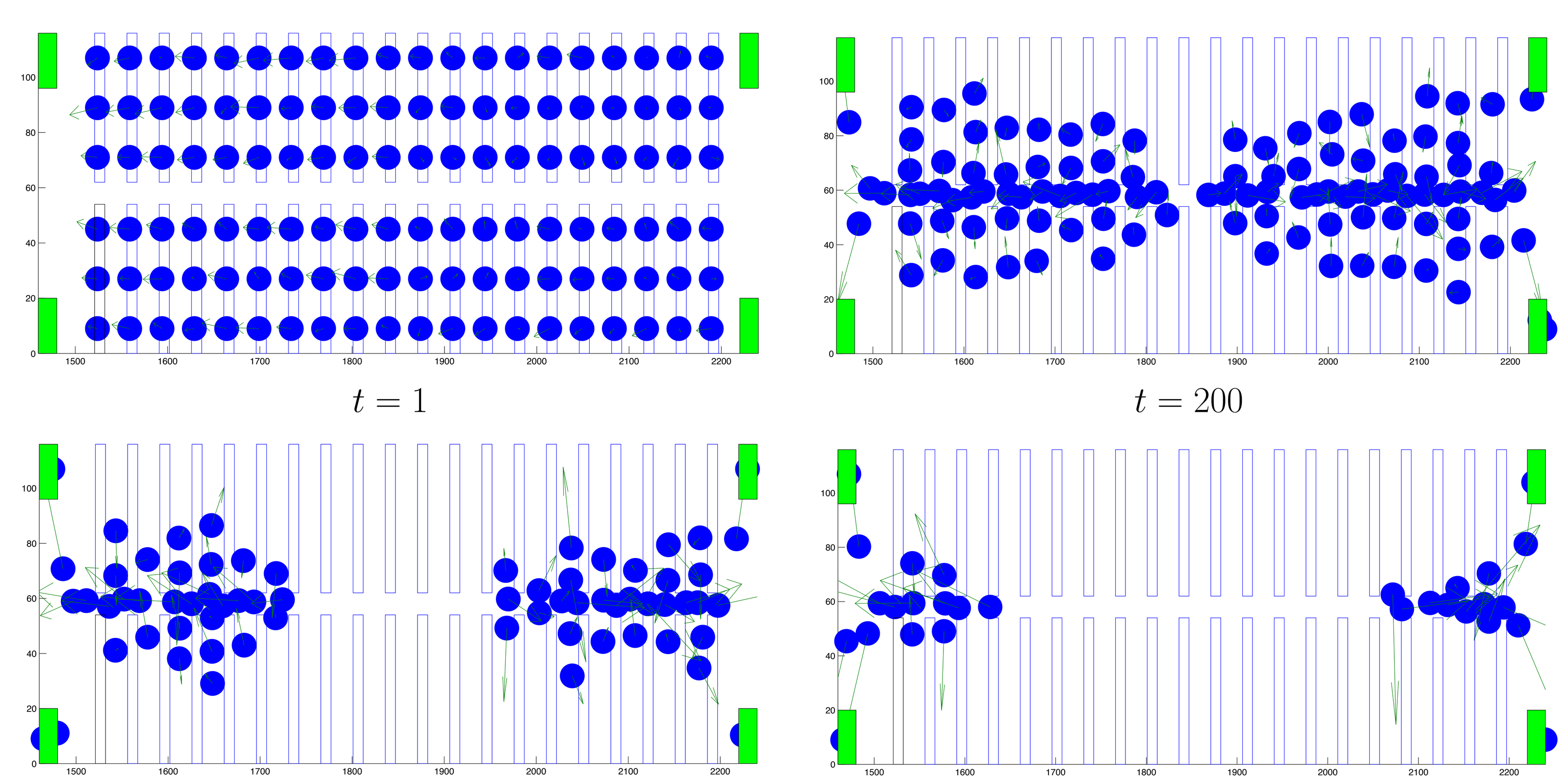


Airplane gradient

Simulations

We consider a simulation of an airplane with twenty rows in total. Each row has six passengers (two groups of three). As visualized in the potential function shown above, the seats and seatbacks have larger values. So initially, the agents have to move forward (to the left) to get off the seats, and then move towards the aisle and then the exits (minimum values in the matrix).

Below are snapshots of the airplane simulation with four exits at $t = 1$, 200, 600 and 1000 iterations.



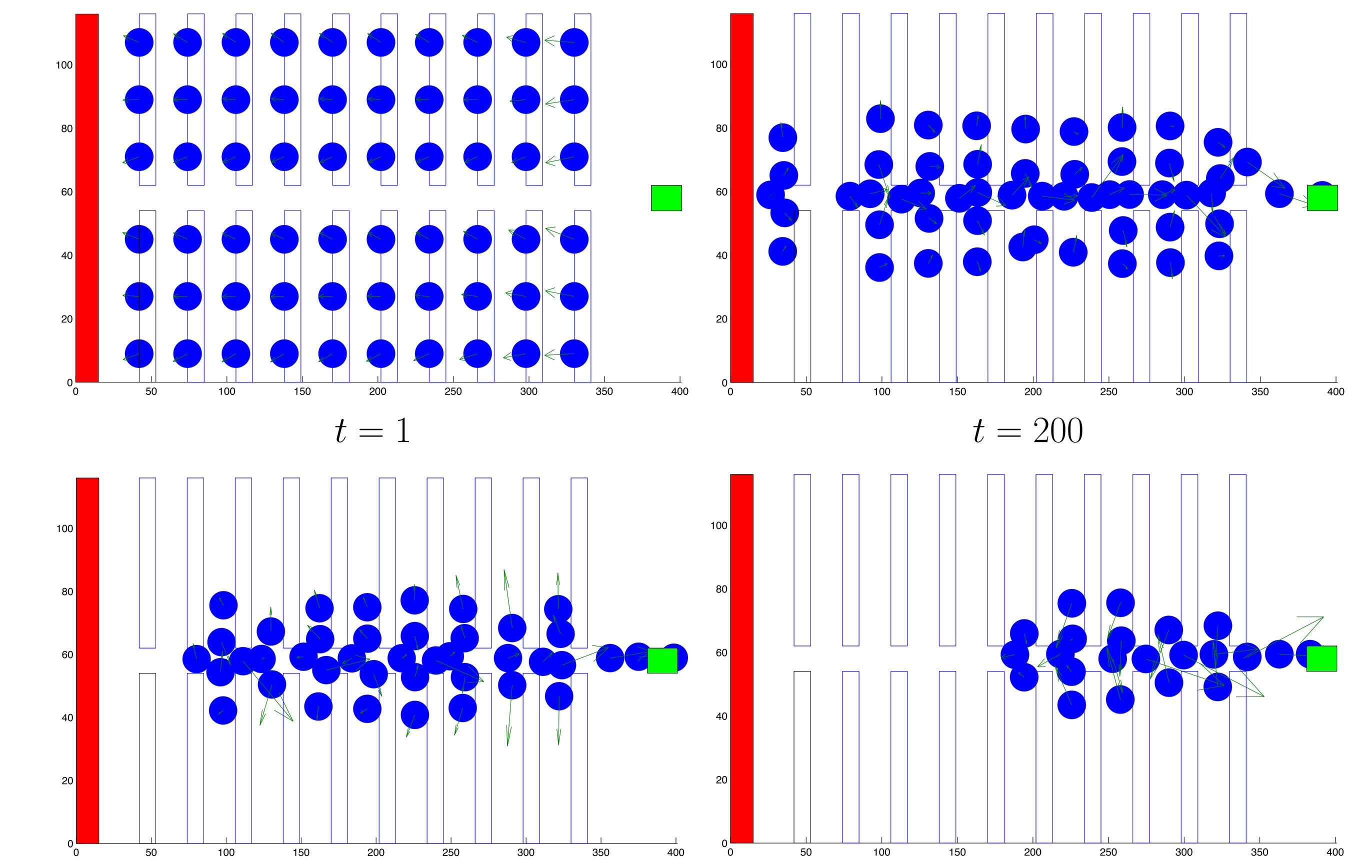
$t = 1$ $t = 200$ $t = 600$ $t = 1000$

Observations:

- Agents in rows row 10 and row 11 have some trouble deciding whether to exit from the front or the back of the airplane since they are equidistant.
- After the agents arrive at the front or the back of the plane, they have some trouble making a decision of whether to go to the exits on the left or right side of the plane.
- Agents in the window seats have trouble moving into the aisles because they are blocked by other passengers. For example, the passenger in 1A is one of the last people to exit the aircraft.
- The whole simulation takes around 1280 iterations to finish.

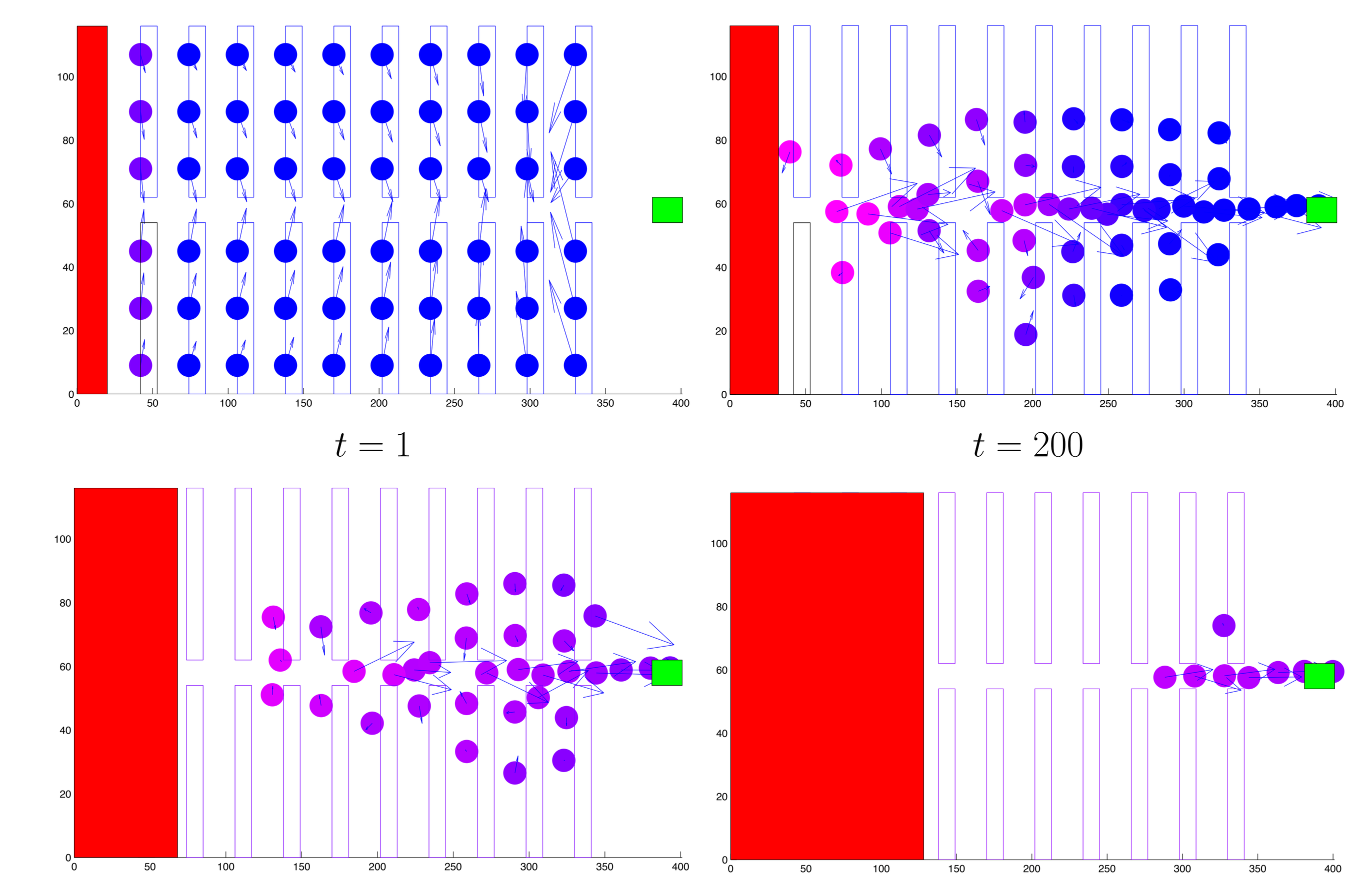
Incorporating Emotion

Below is a comparison of the model with and without contagion for a simplified airplane landscape. In each case, there are ten rows in total and one exit at one end of the aisle. The red section represents a fire (maximum points in the matrix) at the front of the airplane that agents are trying to avoid. In the non-contagion model, it takes about 1180 iterations for the whole swarm to evacuate the plane. Below are snapshots of a simple plane simulation with no emotion at $t = 1, 200, 400$ and 800 iterations.



$t = 1$ $t = 200$ $t = 400$ $t = 800$

In the contagion model, each agent updates its emotion q in additional to its velocity v and position x. The red section represents fire that spreads linearly in time.It takes around 960 iterations for the swarm to evacuate the aircraft with emotion factor involved. Below are snapshots of a simple plane simulation with emotion at $t = 1, 200, 400$ and 600 iterations.



$t = 1$ $t = 200$ $t = 400$ $t = 600$

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